Visualization of Uncertainty and Ensemble Data: Exploration of Climate Modeling Data with integrated ViSUS-CDAT Systems

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Summary

Climate scientists are working towards a better understanding of global climate change. Important scientific thrust areas are to better understand long-term climate impact on terrestrial life and how to mitigate these impacts and adapt to future climate conditions. To help estimate climate change, scientists perform ensemble runs, which consist of many runs of several numerical models using perturbations of input parameters and initial conditions. These ensemble runs produce massive amounts of data and give rise to the challenge to our team — to visually and analytically assist scientists in their mission to understand and estimate long-term climate change. Moreover, we are developing new capabilities for visual exploration and analysis of data collections and uncertainty information. In addition, we are creating production-quality software that is integrated into the Program for Climate Model Diagnosis and Intercomparison's (PCMDI's) globally accepted Climate Data Analysis Tools (CDAT).

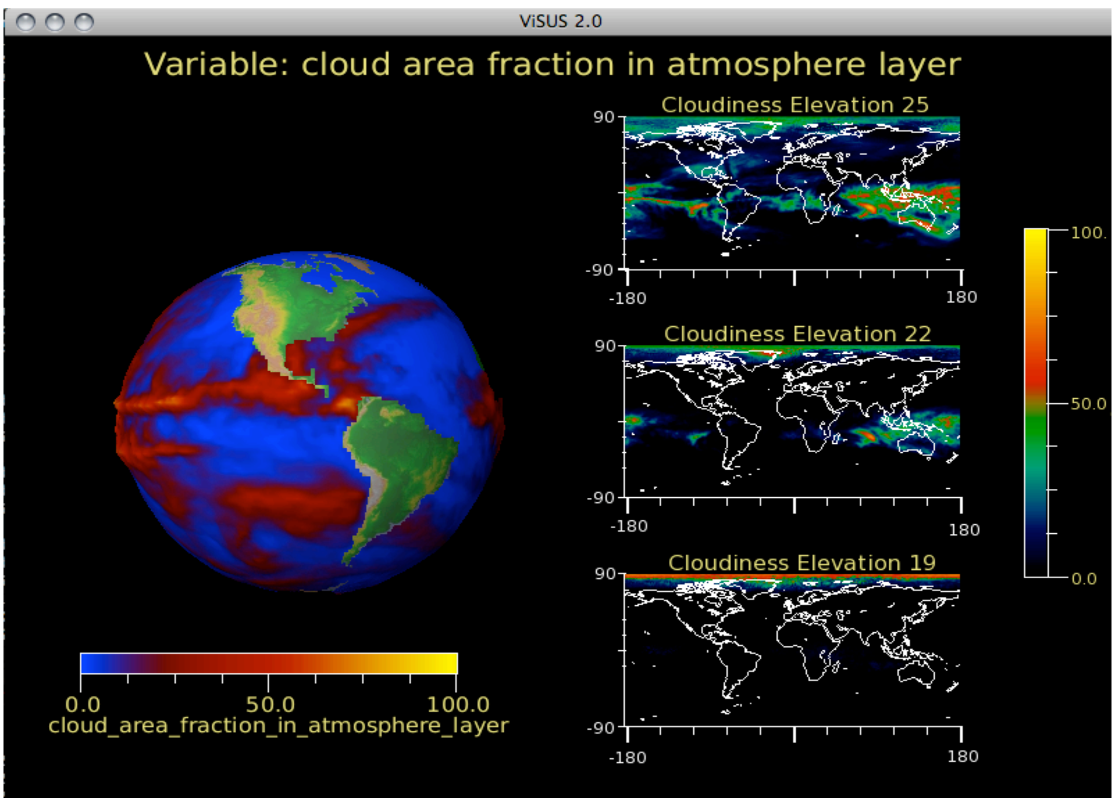

Figure 1. Screenshot of ViSUS 2.0 executed within CDAT. ViSUS provides the user with multiple views for data exploration and analysis. This lets the user investigate multiple variables simultaneously, as well as understand the uncertainty of a single variable. Here, the mean of the cloud area fraction is presented on the left as height on the globe and further highlighted with a redundant colormap. On the right, three elevations of cloudiness are presented using three 2D slices.

Climate scientists are generating large, complex datasets to model global changes in climate over long time periods. Such datasets combine processes underlying climate behavior such as the global carbon cycle, atmospheric chemistry, vegetation, and ocean dynamics.

In order to better understand the long-term trends in climate change, it is essential to characterize the confidence and accuracy of the simulations used for this purpose. For this reason the datasets generated by climate scientists consist of multiple simulations runs, each run using perturbed parameters and input conditions. The result is an *ensemble* dataset, which is a collection of hundreds of simulations estimating possibly hundreds of variables per grid point, across time. These datasets quickly become quite large, on the order of terabytes of data. Such datasets are therefore challenging both in data management and analysis.

Ensemble datasets, by design, provide insight into *uncertainty.* Uncertainty can be described as the accuracy or confidence associated with the data. Errors can arise in the simulation through faulty estimations of the initial conditions, finite resolution of the numerical model, and sensitivity to input parameters.

The focus of this work is to develop and enhance a production-quality data analysis and visualization tool in collaboration with the *Earth System Grid Center for Enabling Technologies (ESG-CET),* the science application for *A Scalable and Extensible Earth System Model for Climate Change Science*, and the climate modeling community in general. The large scale and high complexity of this type of data, data management and visualization is challenging. Our solution is founded on the tight integration of 3D visualization tools, statistical data analysis techniques and compelling metaphors that facilitate the user intuition about the uncertainty of large, multivariate, time-varying datasets.

Figure 1 demonstrates a scripted visualization template generated with the ViSUS system, designed to integrate 3D visualization capabilities into the *Climate Data Analysis Tools (CDAT)* package. CDAT is specifically designed for the needs of climate scientists, providing advanced data analysis capabilities combined with the ability of reading specific data formats and providing geospatial information. The integration with ViSUS provides (among other things) a flexible system for the visualization of large ensemble datasets. Data can be displayed using a variety of techniques, including methods familiar to domain experts. 2D visualizations of the data allow for the direct comparison of multiple variables, or the variation of some dimension of a single variable. Visualizing data on the globe provides a compelling presentation, and integration with more complex 3D techniques such as iso-surfacing. Uncertainty can be displayed for example by using height and color maps, providing visual assessment of the confidence. In addition, the time component of the data can be explored by animating the datasets through each time step.

Within the CDAT framework, the VACET and ESG-CET teams are working on advancing the 2D and 3D capabilities of the ViSUS system for the advancement of climate researcher. To this end, we are working to improve visualization techniques including visual data analysis and sophisticated user interaction. We have Python scripts to facilitate the quick interchange of data sets and provide simple initial visualization settings for the user. The integrated ViSUS-CDAT system is designed to help further scientific discovery by providing a complex visualization tool in a manner directly accessible to the researchers in need.

Thus far, VACET and ESG-CET researchers have "just scratched the surface" of what is possible. Future work will include adapting more advanced visualization and full integration of the ViSUS large data management capabilities within the CDAT system for the benefit of the climate research community.

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